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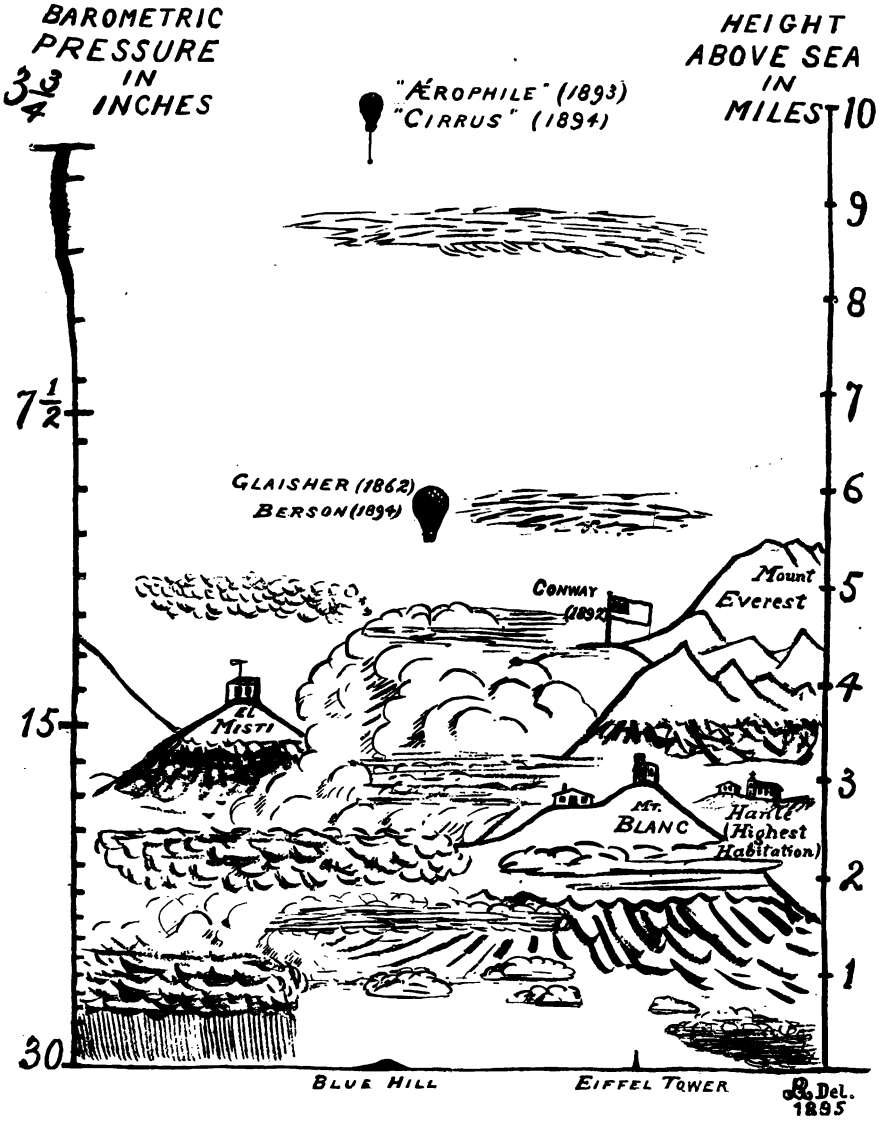
Studies of the Upper Air

BY

A. LAWRENCE ROTCH

From the
Boston Commonwealth
April 6, 1895

COMPARATIVE ALTITUDES



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STUDIES OF THE UPPER AIR.

THE METHODS EMPLOYED AND RESULTS ATTAINED.

(A. LAWRENCE ROTCH before the Boston Scientific Society, March 26, 1895.)

THE chemical constitution of our atmosphere was long ago determined, and although the new element *Argon* has lately been found in it, yet the inertness of this constituent renders it of no chemical and of little physical importance. Aeronauts and mountaineers used to collect samples of air at high altitudes for analysis, but we now know that the composition of the atmosphere is everywhere the same, except for the admixture of more or less carbonic acid gas, aqueous vapor and other impurities. We know, too, theoretically, that with a constant temperature its pressure would be halved for each 3½ miles of ascent, and practically, in the actual case of temperature decreasing with altitude at the rate of about 17° Fahr. per mile, the diminution of pressure is still more rapid, while towards the limit of the atmosphere the temperature must be very low—far below any temperature on earth. Regarding this limit we have only indirect evidence, such as its reflection of the light of the sun when that luminary is below the horizon and the resistance which causes meteors to become luminous on entering it. The height of the atmosphere calculated from these data varies from 45 to 100 miles, and if we accept the hypothesis that the aurora is an electrical discharge within a very tenuous atmosphere, we must consider this to extend several hundred miles above the earth. The kinetic theory of gases, however, affords evidence that the molecules of oxygen and nitrogen in the atmosphere do not escape from the region of the earth's attraction, and that, therefore, inter-planetary space is not filled with an extremely rarified gas.

However interesting these speculations are to physicists, meteorology, which is the most practical science of the atmosphere, is concerned with the portion within ten miles of the earth which embraces 8-9 of the mass of the whole, and it is of this that I shall speak.

Man has seldom penetrated into the stratum above 4 miles, and of course the rarefaction of the air, whose pressure at a height of 10 miles is less than 1-9 of the pressure at sea-level, is the chief obstacle to its exploration by beings like ourselves. Twice during the past 33 years men have reached a height of about 30,000 feet in balloons; they have climbed in the Himalayas to an altitude of nearly 23,000 feet and, in each case, have observed the temperature and pressure during the few minutes they remained at these altitudes. Quite recently, instruments to record automatically these and other elements have been placed

on the summit of a quiescent volcano in Peru above 19,000 feet, from which it is hoped to obtain fairly continuous records. Latterly, also, other attempts in France and Germany have been made to gain information as to the temperature of still higher strata by liberating small balloons carrying no aeronauts but only self-recording barometers and thermometers. From the tracings of the former instruments, recovered when the balloon lost its buoyancy and fell to the ground, it was found that a height of about 10 miles had been reached in two instances.

At my own observatory at Blue Hill and also in Sweden, trigonometrical measures of the highest clouds (those of the cirrus type, composed of snow or ice crystals) showed that they sometimes float 9 miles above the earth. The so-called luminous clouds, similarly measured at night some years ago near Berlin, had an altitude of 50 miles; but these were probably only particles of dust still illumined by the sun at midnight. These various methods will be discussed in detail later and we will first consider the necessity for them.

One of the greatest drawbacks to a full understanding of meteorological phenomena is that the observations on which we base our knowledge are generally made close to the ground in the most restricted air-stratum, whereas the general atmospheric movements, both in velocity and direction, are much modified in the lower strata, and the air surrounding and in contact with the earth differs greatly both in temperature and humidity from the free air. The more strongly agitated upper strata react on the lower in many ways, and a knowledge of the movement of the moderately high atmospheric layers is of great importance for the theory of the general circulation of the atmosphere, and practically for our weather forecasts, since the forces which develop storms have their origin and sphere of action within two or three miles of the earth.

If the atmosphere were only in complete equilibrium, then the few irregular observations, as regards time and place, which have been made in balloons, would give some data on which to base general laws; but, in the actual condition of continual movements and changes in the atmosphere, this can never suffice, and the continuous observations required of all the elements, at all seasons and in all weathers, can only be made on mountains, even though the conditions there only approximate to those of the free air. In this way observations on mountains complete those of the usual low-level stations.

When the earth's surface rises in plateaux, the advantage of elevation above the sea—that is to say, the immersion in the upper strata—is almost entirely neutralized, because still our instruments are placed in air masses which are affected by contact with the earth. For this reason meteorological observatories should be located on high and isolated peaks. The erection of such stations and the discussion of their observations during the last 15 years have contributed largely to the rapid progress of the science of meteorology.

The chief first order stations (those possessing self-recording instruments or where observations are made on an extensive scale) which are located on mountain tops in the various countries will now be briefly described.

The first summit station in the world was that established in 1870,

jointly by the U. S. Signal Service and Prof. J. H. Huntington, on Mount Washington, N. H., 6280 ft. above the sea. Probably nowhere else in the world has such severe weather been experienced, the lowest temperature being here often accompanied by the highest winds, unlike the calms which prevail with intense cold at low levels. For instance, in February, 1886, with a temperature of 50 degrees below zero, a wind velocity of 184 miles an hour was recorded on Mt. Washington. The government meteorological station on Pike's Peak, at an elevation of 14,134 feet, was for many years the highest in the world. Now both these stations are closed, so that there seem to be actually in the United States but two summit stations where meteorological observations are made throughout the year, viz: The Lick Observatory, on Mount Hamilton, Cal.—primarily astronomical--and the Blue Hill Meteorological Observatory in Massachusetts, situated at a very moderate elevation. Prof. S. P. Langley's important researches on the nature and amount of solar heat received by the earth were carried on in 1881 upon Mt. Whitney, Cal., whose summit is 14,500 ft. above the sea.

It is also due to one of our own institutions that the highest meteorological station in the world is now in Peru, where the Harvard College Observatory, several years ago, established an outpost at Arequipa. In 1893, Professor Bailey succeeded in placing self-recording instruments on the summit of the neighboring volcano of El Misti, 19,300 ft. high, when a former station on the side of Mt. Chachani, near the snow line, at an elevation of 16,650 feet, was abandoned. It is impossible for persons to remain at these stations, so they were provided with automatic instruments which should give a continuous record of the chief meteorological elements during two weeks. Several times a month one of the Observatory staff climbs the mountain in order to wind the clocks and change the register sheets, at the same time making a check reading of standard instruments. Breaks in the record occur, owing to unforeseen stoppage of the instruments or inability to make the ascent at the appointed time.

France stands unrivalled in her superb chain of summit stations on the Puy de Dôme (4,800 ft.) in Auvergne, on the Pic du Midi (9,440 ft.) in the Pyrenees, on the Mont Ventoux (6,250 ft.) in Provence and on the Aigoual (5,150 ft.) in the Cevennes, whose construction has cost the National and Provincial governments hundreds of thousands of dollars and years of time. They are generally defective in having no co-operating base stations, and their observations have not been published in detail. In 1890, M. Vallot, a devoted Alpinist and meteorologist, established several stations on and near Mont Blanc, from which records have been obtained each summer since. The highest of these stations, at the Rochers des Bosses, 14,320 ft., is provided with many self-recording instruments operating two weeks without attention, which are looked after by the owner or his guides each week or two during the summer. The much talked of Observatory of M. Janssen, sunk in the snow on the very top of Mont Blanc, 1460 ft. higher, is not yet in operation, but a meteorograph costing $3000 has been made for it in Paris which will continuously record all the meteorological elements during a period of 3 months without attention. A similar instrument is being

constructed at Blue Hill by Mr. Fergusson for Professor Pickering's station on El Misti, at less than 1-5 the cost of the French instrument.

On the Eiffel Tower in Paris are instruments 980 feet above the ground, which give more nearly the conditions prevailing in the free air than do any others permanently at this elevation. They record at the Central Meteorological Office, a quarter of a mile distant, side by side with similar instruments exposed near the ground.

Among the German and Austrian stations, that on the Sonnblick, a peak of the Austrian Alps, 10,170 ft. high and the highest permanently occupied observatory in Europe, stands pre-eminent, having furnished very valuable results under Dr. Hann's direction.

Switzerland, which since 1873 had maintained stations in mountain passes, etc., has now on the Säntis (8,200 ft.) in the Canton of Appenzell, one of the best located and equipped summit stations in the world; and in Italy an observatory on Monte Cimone (7,100 ft.) in the Apennines, near Lucca, has recently been completed.

On Ben Nevis, the highest mountain of Great Britain, (4,400 ft.), there is a remarkable station where during ten years an unbroken series of hourly observations has been maintained. There is a base station at sea-level, and the advantageous situation on the west coast of Scotland renders the results of the observations, which have been discussed by Dr. Buchan, of great value.

It is impossible to even enumerate all that has been gained from these high-level observations, but the chief results attained, or still sought, may be thus summarized: Determination of normal decrease of temperature and humidity with elevation; abnormal changes with elevation in cyclones (or areas of low pressure near the ground) and in anti-cyclones (or areas of high pressure near the ground); height to which these cyclones and anti-cyclones persist and the circulation of the air around each at various levels.

But wind, temperature and moisture observed on mountains do not represent those prevailing at the same level in the free air, which a balloon, carried by the air itself, influences in a very much less degree than does a mountain. This, and the desire to attain a greater height than is possible on mountains, is the plea for the employment of balloons in meteorology; but it was the latter consideration alone which probably first led the scientists of all nations to make balloon ascents.

As the first mountain-top station was in New England, so the first scientific balloon ascent was undertaken in 1784 by a Bostonian, Dr. John Jeffries, then residing in London. He observed the barometer, thermometer and hygrometer, and his successors did the same with little improvement in apparatus. In order to obtain true air temperatures it was – and is by many aeronauts — thought sufficient to hang a thermometer in the basket of the balloon or above it, so that, owing to defective instruments and exposures, balloon ascents, until recently, were productive of little good to meteorology. Among the most famous ascents of this century was that of Gay Lussac, who in 1804 reached 23,000 ft., that of Barral and Bixio in 1850 and of Welsh in 1852, in both of which nearly the same altitude was attained. In 1862, the English aeronauts, Coxwell and Glaisher, became unconscious at 29,000 ft., and in 1875 this height was nearly

equalled by the French aeronauts, Crocé-Spinelli, Sivel and Tissandier, when the two former were asphyxiated, although a supply of oxygen was carried to assist respiration. This fatal accident served to check further high ascents until last year.

Captive balloons were, however, employed considerably both in France and England, and the temperature decrease investigated up to heights of a thousand feet. Such balloons cannot be used in high winds, since they are driven down to the ground. For this and other reasons they are inferior to the tower which now exists in Paris.

It is due to the German Aeronautical Association, and to Dr. Assmann of Berlin in particular, that more trustworthy methods of observing temperature and humidity were devised. By means of an instrument called the aspiration psychrometer, hung outside the balloon, and in which a current of air is drawn past the bulbs of the wet and dry bulb thermometers, enclosed in polished metal tubes to cut off the direct solar or reflected heat rays, the great errors of the ordinary methods are avoided. These arise from lack of ventilation — since the balloon is relatively in a calm and air may be brought up from the earth in the basket almost like water in a bucket — and from the consequent heating of the thermometer, either directly by the sun or by radiation from the heated gas-bag.

As an illustration of modern methods of observation, there may be mentioned an interesting series of observations in Berlin in 1892, in which the writer assisted, where observations at three different levels were taken simultaneously. On the ground were placed self-recording instruments; in a captive balloon, 2000 ft. above the earth, an aspirated meteorograph recorded automatically temperature, pressure and humidity; while in the free balloon Dr. Berson and the writer observed the barometer, the aspiration psychrometer, etc. There being little wind, our balloon floated over Berlin at an average height of 3,600 ft., so that the three sets of observations, nearly vertically over one another, permitted the changes of temperature and humidity in the stratum of air ¾ of a mile thick to be deduced.

The very reason which makes temperature determinations in bal loons difficult, because the balloon takes the velocity of the current in which it floats, furnishes a perfect method of ascertaining this velocity, when moving horizontally, for it is only necessary to note the times of passing over landmarks whose locations are known.

Dr. Berson last year ascended alone to perhaps the highest point ever reached by man; certainly his barometer reading of 9.1 inches, corresponding to an elevation of approximately 30,000 ft., is the lowest ever made. At this height of nearly 6 miles, the aspirated thermometer read 54 degrees below zero, Fahr. and one exposed to the sun's rays no more than 11 degrees below zero. Dr. Berson inhaled oxygen at times and suffered little from this extraordinary ascent. The chief results attained were:

(1) The determination of an extremely low temperature at the highest point at which observations have been made, and a much more rapid decrease of temperature between one and 6 miles than has been assumed for winter.

(2) Inversion of temperature — that is, a rise of temperature with elevation — in the morning and evening between the earth and one mile above it.

(3) The very feeble insolation; the great humidity of the upper strata and the fine haze which extended up at least 6 miles.

(4) The snow-flake structure of the cirro-stratus clouds, formerly considered to be composed of ice-crystals.

(5) The great increase of wind velocity, from nearly a calm at the earth's surface to 36 miles per hour at the average elevation of the balloon.

By means of small free balloons, carrying no aeronaut but only self-recording instruments, the temperature has been approximately determined 10 miles above the earth. The first trials made by M. Hermite in France gave somewhat unsatisfactory temperature determinations, owing to unsuitable instruments, but a probable height of 10 miles was reached by his balloon called *L'Aérophile.*

The German Aeronautical Association has lately occupied itself with these balloons and one of them, the *Cirrus*, last July reached a height, as computed from its aneroid barometer record, of over 10 miles, travelling 650 miles in 10 hours and then falling to the ground with its instruments uninjured. The Society being notified by the finder, according to a polyglot request on the balloon, it was recovered and brought back to Berlin.

In order to avoid freezing of the ink in a register pen at the extremely low temperature which it was supposed might be encountered, an alcohol thermometer was arranged to record by photography, while the intense action of the sun upon the thermometer undiminished by atmospheric absorption at these great altitudes, was neutralized by a current of air induced by an exhaust fan which was driven by a weight attached to a cord hanging from the balloon. With a barometric pressure of 3.3 in. (less than 1-9 of that at the earth's surface and indicating a height of about 10 miles), a temperature of 64 degrees below zero Fahr. was recorded. A greater height and a lower temperature were probably reached, but the barometer register was not graduated lower, and owing to the stoppage of the aspirator the recorded temperatures were undoubtedly too high.

Prof. Harrington, the Chief of the U. S. Weather Bureau, is an advocate of the use of balloons at heights which can be reached by man as a means of increasing our knowledge of the condition of the free atmosphere and thereby improving weather forecasts. He believes, however, that this is a subject for private investigation, and that the government would not be justified in expending large sums of money in experiments which might not at first, at least, bring adequate returns. It must not be understood, however, that the Chief of the Weather Bureau indorses Prof. Hazen's sanguine project of an air ship which, equipped with all means known to science, shall carry him and other explorers to the greatest heights ever reached.

Two investigations which have been commenced at the Blue Hill Observatory by Messrs. Clayton and Fergusson on the thermal conditions of the free air near the ground and on the movements of the air currents in various types of weather up to 9 miles above it, promise very valuable results.

The first employment of kites for elevating meteorological instruments was in England by Mr. E. D. Archibald, who attached anemometers to kites flown in series and attained a very considerable altitude.

Last summer, Mr. W. A. Eddy,

who had experimented with the Malay or tailless kites flown tandem, came to Blue Hill and with the assistance of Mr. J. Ritchie, Jr., a very light thermograph was raised by the kites 1400 ft. above the top of the hill, as determined by angular measurements at the end of a base line. The elevation corresponds to over 2000 ft. above sea level, and the kites remained at a somewhat lower altitude for several hours. Good temperature records were obtained, permitting the temperature decrease in the strata of air between the kites, the summit and the valley stations, to be determined. The kites gave indications of ascending currents under cumulus clouds and of great aerial eddies above and around the hill, which were quite unsuspected.

Kites used in this manner furnish a cheap and ready means of exploring the atmosphere within a mile or more of the earth. Other instruments can no doubt be elevated by the kites, which possess advantages over captive balloons not only in economy, but because they fly better in high winds, although by the device of attaching them in series they may be flown in very light winds.

Soon after the establishment of the Blue Hill Observatory in 1885, measures of the relative velocity and direction of motion of clouds were commenced and are still continued. In 1890–1 many trigonometrical and other determinations of the heights of the various species of clouds were made, which permitted the relative velocities to be expressed in actual velocities. Direct measurements with the theodolites showed the highest clouds — those of the cirrus or feather type — to be occasionally 9 miles high and sometimes in the winter to travel 230 miles an hour; for the Blue Hill observations indicate that the entire atmosphere, from the lowest to the highest level, moves almost twice as fast in winter as in summer. The average height of the cirrus during the year is about 29,000 ft., or less than six miles, and the mean velocity is 89 miles an hour, showing, in connection with similar observations on lower clouds — such as the alto-cumulus and alto-stratus — that between 2 and 9 miles there is an almost continual westerly current of great velocity, a comparison of the average velocities at different heights indicating that from the lowest to the highest clouds the increase of velocity is a linear function of the height.

Of course, observations of clouds for determining the motions of the upper air currents have objections; for often no clouds are visible or the lower strata obscure the upper clouds, while observation confounds the actual movement of the cloud with the extension of the conditions which form it. Yet, such a method remains the only one for a systematic study of these currents, and a discussion which Mr. Clayton has undertaken of all the Blue Hill observations will throw a great deal of light upon the obscure movements of the air at various heights around centres of high and low barometric pressure, as they appear to us on the earth, and cannot fail to be of practical use in weather forecasting.

Still another method of studying the upper air current has been tried by M. M. Montigny and Ventosa in Europe and by Mr. A. E. Douglass, now at the Lowell Observatory in Arizona. Mr. Douglass used a telescope with an 18-inch objective, and when a planet was looked at, frequently fine lines or waves were seen moving across the disk, which were due to the air currents. Their height could be roughly calculated

from the focal adjustment of the eyepiece, and their velocity from the rate at which they passed across the field of view. This method, although valuable as a means of testing the atmospheric conditions suitable for astronomical work, does not seem capable of giving the exact data as to the upper currents which are required for meteorological conclusions.

In closing this review of the various methods available for the study of the upper air, it will be seen that observations on mountains are still the only ones capable of being made of all the elements at all times, although clouds can be observed very often and their systematic study will eventually be recognized as necessary for weather forecasting. Occasionally, observations in captive balloons and with kites will furnish reliable data in special cases when it is desired to investigate the conditions prevailing in the free air near the earth, but the necessarily infrequent observations which can be made at high altitudes in balloons carrying aeronauts, or the few automatic records obtained from unmanned balloons which may reach still greater altitudes, will hardly do more than elucidate the general conditions reigning towards the top of the great aerial ocean.

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